CHARACTERIZATION AND APPLICATION OF THE μA703 IN A FOUR-STAGE FM IF AMPLIFIER

by David Bingham

INTRODUCTION

The μA703 is a linear integrated circuit designed to give very high available unneutralized power gain at 10.7 MHz and to have the capability of current mode limiting with a suitable choice of output load conductance. The advantages of current mode limiting are:

a. The loads presented to the transformers by either the input or the output of the μA703 do not change appreciably under any normal input signal (i.e., up to approximately 3 volts rms).

b. Since there is no breakup or phase distortion of the signal, no AGC is required for an FM IF amplifier.

c. The passband characteristics of the transformer are unaltered during any stage of limiting.

The performance of an IF amplifier employing current mode limiting is therefore characterized by a very low capture ratio, excellent AM rejection, and the ability to accommodate rapidly fluctuating signal strengths (as with a car radio).

In this report, the μA703 will be discussed with special reference to current mode limiting amplifiers for use at 10.7 MHz. Then a design for a four-stage high-quality FM IF amplifier will be described in detail.

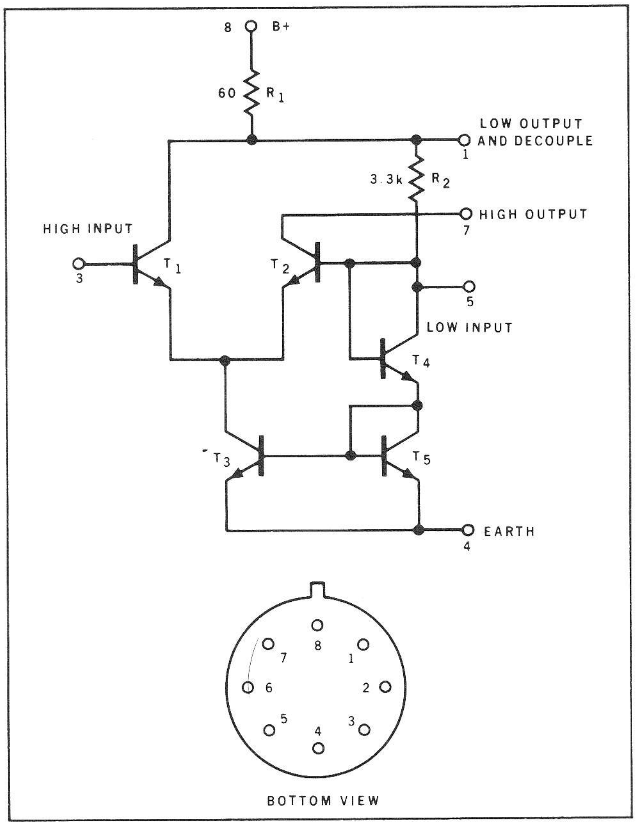

Fig. 1. Linear integrated circuit μA703.

μA703

The μA703 is shown schematically in Fig. 1. T_1 and T_2 act as an emitter-coupled pair of transistors and constitute the active RF amplifier. T_3, T_4, and T_5, together with R_1 and R_2, are used to provide the biasing for T_1 and T_2. In the following description of the biasing of T_1 and T_2, T_1 and T_2 together with T_3 and T_5, will be considered as perfectly matched pairs of transistors. This matching is achieved because all the transistors are manufactured on a monolithic chip, which results in identical diffusion schedules for all the transistors. Also, because of the close proximity of the transistors contained on a chip, the tolerances in manufacturing can be minimized.

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The current through the biasing chain (R_2, T_4, and T_5) is approximately equal to the B+ supply minus the two emitter voltage drops of T_4 and T_5 (i. e., 1.5 volts) divided by 3.3 Kilohms. For a 12-volt supply, this current will be a little over 3 milliamps. Since T_3 and T_5 are identical transistors, the V_{BE} - I_C characteristics will be identical. Therefore, neglecting the base currents in T_3 and T_5, the collector current of T_3 is approximately equal to the current in the biasing chain. Due to its very high output impedance, the T_3 acts as a current source to the identical pair of transistors T_1 and T_2. In a practical amplifier, the bases of T_1 and T_2 will be tied together through a transformer or choke so that the current defined by T_3 will be equally divided between T_1 and T_2.

The total current consumed by μA703 is approximately equal to twice the current through the biasing chain or four times the current through either T_1 and T_2. The function of T_4 is to provide a sufficiently high bias voltage for T_1 and T_2, so that there is no possibility of T_3 being driven into saturation. If T_3 were driven into saturation, it would no longer act as a current source to T_1 and T_2.

Considering the μA703 as an amplifier, the output impedance of T_3 appears almost infinite in value at medium to low frequencies, and the base of T_2 almost a short circuit to ground (the series resistance of T_4 and T_5 is only a few ohms).

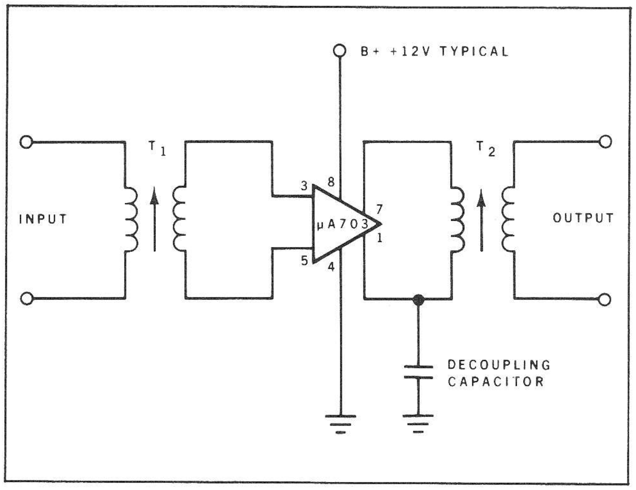
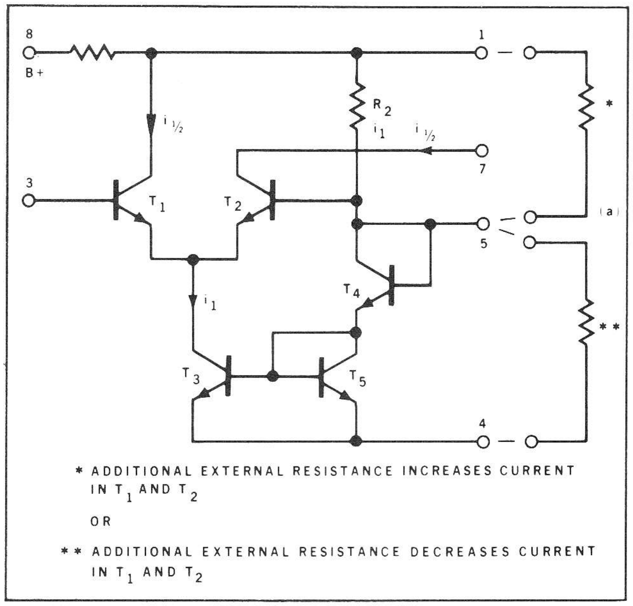


Fig. 2. Practical amplifier.

Fig. 2 shows the use of μA703 as a high-frequency amplifier. The only external components are the tuned transformers plus one decoupling capacitor. The supply voltage will normally be chosen between about 6 to 12 volts. The current through transistors T_1 and T_2 will be within these limits of supply voltage, approximately proportional to the supply voltage. If desired, the current in T_1 and T_2 may be increased by adding an external resistance in parallel to R_2 or may be decreased by adding an external resistance across T_4 and T_5. (See Fig. 3.)



* ADDITIONAL EXTERNAL RESISTANCE INCREASES CURRENT IN T_1 AND T_2

OR

** ADDITIONAL EXTERNAL RESISTANCE DECREASES CURRENT IN T_1 AND T_2

Fig. 3. Alternate No. 1 amplifier configuration.

Another possible circuit configuration is shown in Fig. 4. In this circuit the available power into a load is doubled, but the high frequency stability limited gain is decreased. Another disadvantage of this circuit is the non-usability of R_1.

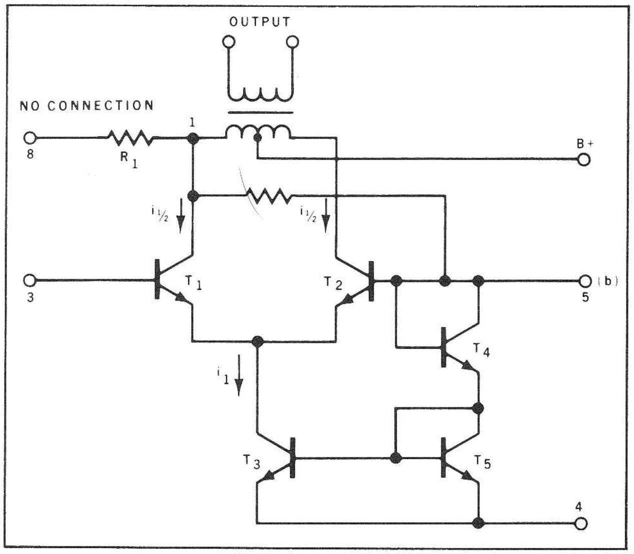


Fig. 4. Alternate No. 2 amplifier configuration.

THE μA703 AS A CURRENT MODE LIMITER

A current mode limiter is one that defines the maximum peak-to-peak output current independently of the load conductance. A single transistor, FET, or tube cannot satisfy the above condition since, as the input signal is increased, the maximum downward output current swing will be the product of:

(V supply - V saturation) x (load conductance), limited primarily by the load conductance.

The μA703, however, supplies a constant current, i_1, from T_3 and T_2. Therefore, the limiting current values of T_2, assuming a low-output load conductance, are either 0 or i_1, no matter how large the input signal is (as long as it does not break down the emitter diode of T_1 in the reverse direction). The load conductance value is chosen for nonsaturating or current-mode operation, so that the downward voltage swing across this load conductance never goes below the fixed base bias voltage on T_2.

DETERMINATION OF OUTPUT LOAD CONDUCTANCE FOR CURRENT MODE LIMITING CIRCUITS

If the input signal (sine wave) is very large in the circuit shown in Fig. 5, the output current will be a square wave of peak-to-peak amplitude of $-i_{1/2}$ to $+i_{1/2}$ to a transformer coupled load. By Fourier analysis, this current can be represented by an infinite series, as follows:

$$I = \frac{i_1}{2} \cdot \frac{4}{\pi} \left\{ \cos \omega t + \frac{\cos 3\,\omega t}{3} + \cdots\cdots \right\}$$

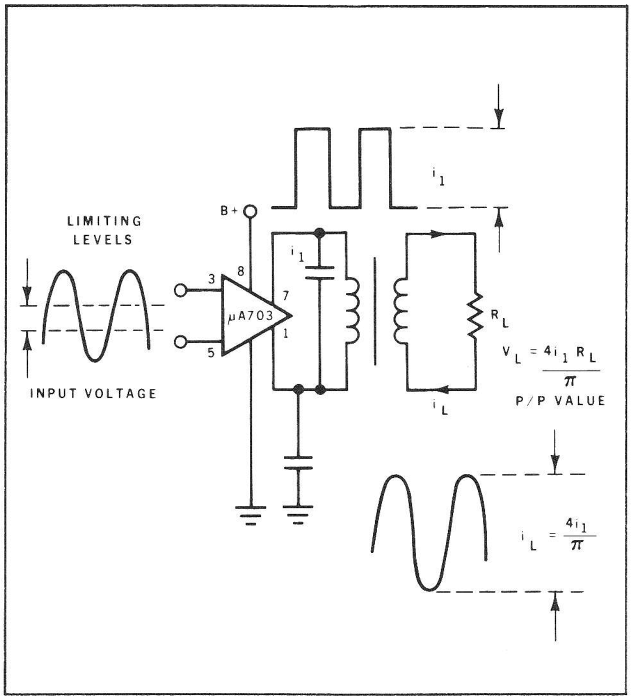


Fig. 5. Voltage and current waveforms for the μA703 in a non-saturating circuit.

The peak value of the fundamental frequency of the square wave has a peak value of $\frac{4}{\pi}$ times the peak value of the square wave.

In most RF applications the required amplifier bandwidth is narrow, and all terms other than the fundamental can be ignored. (FM IF transformers can be assumed to have negligible response at three times the IF frequency, or 32.1 MHz and higher frequencies). The voltage occurring across the load conductance is therefore sinusoidal, although the output current from the μA703 is a square wave.

The maximum load conductance can now be defined by:

$$\frac{\text{(peak downward current swing)}}{\text{(Supply voltage)} - \text{(Voltage across } T_4 \text{ and } T_5\text{)}}$$

$$= \frac{i_{1/2}}{\text{Supply Voltage} - 1.5} \times \frac{4}{\pi}.$$

In a practical design, the load conductance should be increased by 50 percent because of the normal tolerances of the load conductance and the variation of i_1 from one μA703 to another.

$$\therefore \text{ Load Conductance} = \frac{3 i_1}{\pi(\text{supply voltage} - 1.5)}$$

$\therefore$ If i_1 = 3ma and V supply = 12 volts, the load conductance becomes

$$Q_L = \frac{3 \times 3}{\pi \times 10.5} = 0.273 \text{ mmho}.$$

NOTE:

1. The load conductance is independent of frequency.
2. If the current i_1 is varied by the addition of an external resistance between pins 1 and 5, as previously mentioned, the load conductance must be recalculated.

INPUT MATCHING CONSIDERATIONS

For optimum design in a current-mode limiting amplifier, the μA703 should be mismatched at the input.

a. The input conductance of the μA703 will be primarily determined by h_{FE} of T_1 at low RF frequencies. The

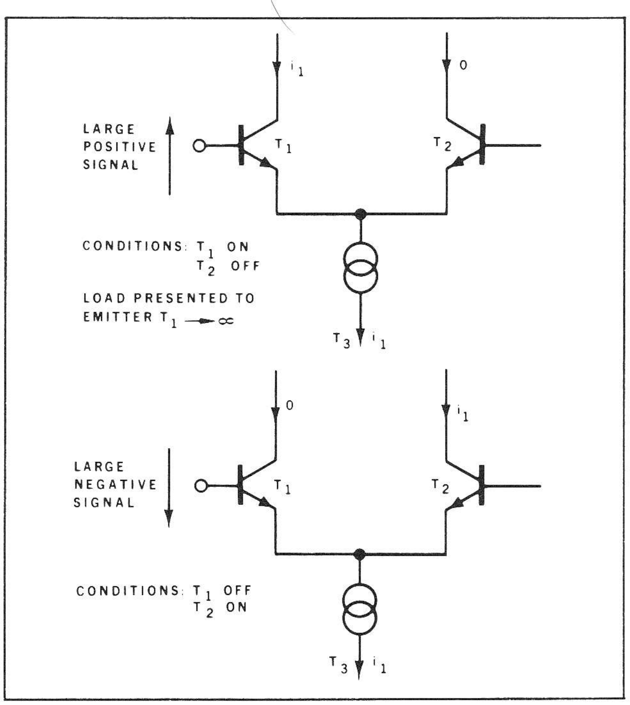


Fig. 6. Large signal operation.

h_{FE} for any transistor family will vary over a substantial range. For the μA703, this range is from 50 to 200.

b. The input conductance will decrease when the μA703 is driven into limiting. This can easily be seen by considering Fig. 6. If a large positive voltage is applied to T_1, then T_2 will be switched off and the total admittance presented to the emitter of T_1 will be very small, thereby decreasing the input conductance. If a large negative voltage is applied to T_1, T_1 will be switched off and the input conductance reduced.

DESIGN OF AN FM IF AMPLIFIER

The requirements for an FM IF amplifier design are as follows:

1. Power gain greater than 85 dB
2. Bandwidth of amplifier to be -6 dB at ± 120 kHz, center frequency; 10.7 MHz together with a linear phase characteristic across the passband.
3. Total harmonic distortion at 400 Hz to be less than 1 percent with ± 75 kHz deviation.
4. Capture ratio to be as low as possible, preferably less than 2 dB.

Typical "y" parameters of the μA703 at 10.7 MHz with a 12-volt supply are:

$$y_{11} = 0.5 + j\,0.8 \text{ mmho}$$

$$y_{22} = 0 + j\,0.23 \text{ mmho}$$

$$y_{21} \approx -25 + j\,0 \text{ mmho.}$$

Due to the very small value of y_{12}, its value can best be determined by the ratio of the forward power gain to the reverse power gain in a carefully shielded jig.

Ratio of forward-to-reverse power gain

$$\left|\frac{y_{21}}{y_{12}}\right|^2 = 93 \text{ dB}$$

or the maximum stable unneutralized power gain

$$\left|\frac{y_{21}}{y_{12}}\right| = 46.5 \text{ dB.}$$

In order to realize the phase and bandpass characteristics of the IF amplifier, three undercoupled transformers ($kQ_{pri} = 0.8$, where k = coupling factor, and Q_{pri} = primary Q factor) each of which having a -3 dB bandwidth of 310 kHz are a satisfactory compromise.

$$\text{If } y \approx \frac{\text{Bandwidth}}{\text{Center frequency}} = \frac{2\,\Delta f}{f_o} = \frac{0.31}{10.7} = 0.029.$$

Then $y\,Q_{pri}$ can be obtained from the standard admittance curves, providing $kQ_{pri} = 0.8$ and $yQ_{pri} = 1.2$.

$$\therefore Q_{pri} = 41.5$$

(assuming equal primary and secondary "Q" factors).

To minimize the effect of the variability of the input conductance of the μA703 on the Q_{sec} of a transformer, the input conductance in the nominal case will be designed so that it will load the unloaded "Q" by 25 percent. The output conductance of the μA703 being extremely low will not affect the Q_{pri} of the transformer.

Assuming the primary and secondary unloaded "Q"s to be equal, the loaded "Q" ratio is

$$\frac{Q_{pri}}{Q_{sec}} = 1.33$$

$$\text{but} \qquad \sqrt{Q_{pri}\,Q_{sec}} = 41.5$$

$$\therefore \qquad Q_{pri} = 48 \text{ (loaded)}$$

$$\text{and} \qquad Q_{sec} = 36 \text{ (loaded)}$$

The input conductance of the transformer with the secondary loaded is given by

$$G_{in} = G_{pri}\left(1 + \frac{K^2 t}{\left\{1 + (y\,Q_{pri})^2 t^2\right\}}\right)$$

$$\text{where} \qquad t = \frac{Q_{sec} \text{ loaded}}{Q_{pri} \text{ loaded}}$$

and G_{pri} = the parallel conductance of the primary of the transformer.

$$K = kQ_{pri}$$

$$\therefore \qquad G_{in} = G_{pri}\left(\frac{1 + 0.8 \times 0.75}{\left\{1 + 1.2^2 \times 0.75\right\}}\right)$$

$$= 1.33\,G_{pri}$$

The load conductance to be presented by the primary of the transformer to the output of the μA703 has been previously determined to be 0.273 mmho for a nonsaturating amplifier.

$$\therefore \quad 1.33\,G_{pri} = 0.273 \text{ mmho}$$

$$\therefore \quad G_{pri} = 0.205 \text{ mmho.}$$

The tuning capacitance necessary to give a Q_{pri} of 48 with a primary conductance of 0.216 mmho:

$$= \frac{Q_{pri}\,G_p \times 10^{-3} \times 10^{12}}{\omega} \text{ pF}$$

$$= \frac{48 \times 0.205 \times 10^9}{2\pi 1.07 \times 10^7} \text{ pF}$$

$$= 146 \text{ pF.}$$

If both the primary and secondary windings of the transformer have the same number of turns and tuning capacitances, the secondary tap to the μA703 is given by:

$$n^2 = G_{pri}\left(\frac{Q_{sec} \text{ unloaded} - Q_{sec} \text{ loaded}}{Q_{sec} \text{ unloaded}}\right) \frac{0.1}{g_{11}}$$

$$= 0.205\left(\frac{48 - 36}{48}\right) \cdot \frac{1}{0.5} = 0.103$$

$$n = 0.322.$$

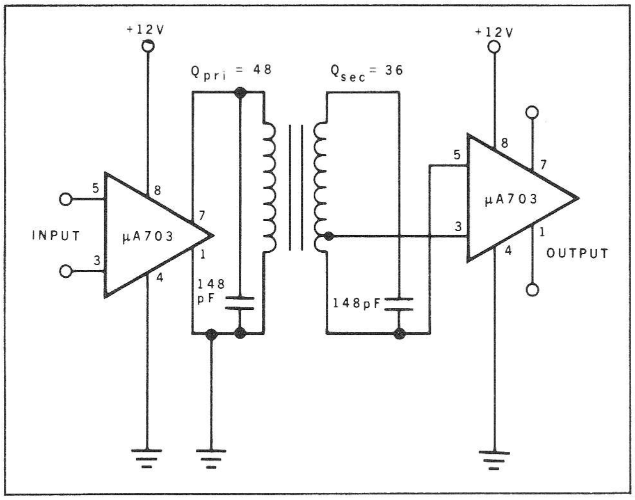


Fig. 7. The complete FM interstage transformer showing interfacing between two μA703's.

Due to cost considerations, a value of tuning capacitance lower than 148 pF is preferred by coil manufacturers. An alternative transformer with 82-pF tuning capacitance is given in Fig. 8,

where $n_p^2 = \frac{82}{148}$

$$\therefore n_p = 0.745$$

$$n_s = n_p \times 0.33$$

$$= 0.246.$$

POWER GAIN CALCULATION

Assuming that the power gain of a stage will be much less than the maximum stable unneutralized power gain, $\left|\frac{y_{21}}{y_{12}}\right| = 46.5$ dB, then the effect of y_{12} can be ignored.

The total reflected conductance at the primary of the transformer of the loaded secondary of the transformer is equal to 0.33 x 0.273 mmho. One-fourth of this conductance is due to the loading of the input of the μA703. Therefore, the reflected admittance of the input of the μA703 at the output of the previous μA703 is:

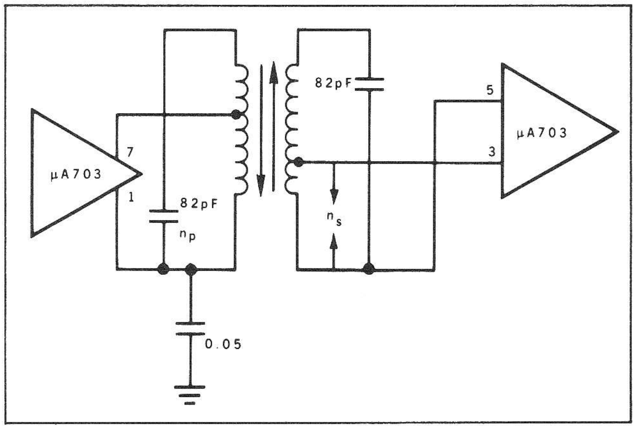


Fig. 8. Alternate interstage transformer.

$$\frac{0.33 \times 0.273}{4} = 0.0274 \text{ mmho}$$

$\therefore$ Power gain =

$$\frac{|y_f|^2 \text{ (reflected input conductance of following } \mu\text{A703}}{g_{11} \text{ (total load conductance)}^2}$$

$$= \frac{25^2 \times 0.0274}{0.5 \times 0.273^2}$$

$$= 460$$

$$= 26.6 \text{ dB}.$$

To satisfy the power gain requirement of the amplifier, four stages are required; resultant power gain is therefore 106 db.

Fig. 8 shows the schematic of the four-stage FM IF amplifier. The detector is a modified ratio detector which, due to the excellent limiting properties of the amplifier, does not require the usual large electrolytic capacitor.

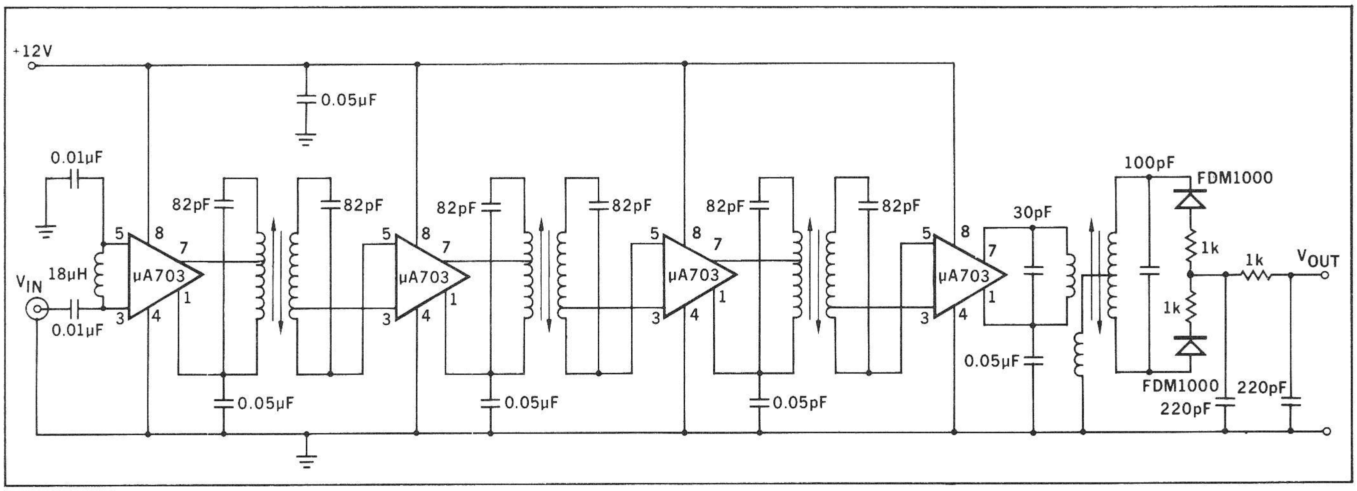


Fig. 9. Four-stage FM IF amplifier employing non-saturating limiters.

PERFORMANCE OF THE AMPLIFIER

The four-stage FM IF amplifier has the following performance parameters.

Sensitivity $< 50\mu V$ for full limiting
Capture ratio < 1.5 dB
Bandwidth of detector ~ 800 kHz
AM rejection > 40 dB.

SUMMARY

The μA703 has been described and an analysis of its operation as a current mode limiter given. Its application in an FM IF amplifier, together with a practical four-stage amplifier, has also been shown. Further applications include very high-gain, unneutralized, small-signal amplifiers up to 200 MHz.

The μA703 should prove to be a useful and economical device for the consumer market, based on its very high frequency power gain, the availability of current mode limiting, the possibility of changing its bias current by the simple addition of an external resistor, and its lack of complicated biasing and decoupling networks.

REFERENCES

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